EO/US
PCT/IL98/00611

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing: 22 June 2000 (22.06.00)	
International application No.: PCT/IL98/00611	Applicant's or agent's file reference: 001/00620
International filing date: 16 December 1998 (16.12.98)	Priority date:
Applicant: BRAUN, Ori, J. et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International preliminary Examining Authority on:

28 February 2000 (28.02.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer: J. Zahra Telephone No.: (41-22) 338.83.38

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PATENT COOPERATION TREATY

RECD 13 MAR 2001 WIPO PCT

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 001/00620	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/IL98/00611	International filing date *(day/month/year)* 16/12/1998	Priority date *(day/month/year)* 16/12/1998
International Patent Classification (IPC) or national classification and IPC G01C3/08		
Applicant 3DV SYSTEMS, LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 10 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 5 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☒ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand 28/02/2000	Date of completion of this report 09.03.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Springer, O Telephone No. +49 89 2399 2619

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:

Description, pages:

1-19 as originally filed

Claims, No.:

1-31 with telefax of 20/02/2001

Drawings, sheets:

1/3-3/3 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
☐ the language of publication of the international application (under Rule 48.3(b)).
☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

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☐ contained in the international application in written form.
☐ filed together with the international application in computer readable form.
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☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

☐ the description, pages:
☒ the claims, Nos.: 32-36

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

IV. Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

   ☐ restricted the claims.

   ☐ paid additional fees.

   ☐ paid additional fees under protest.

   ☐ neither restricted nor paid additional fees.

2. ☒ This Authority found that the requirement of unity of invention is not complied and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

   ☐ complied with.

   ☒ not complied with for the following reasons:
   see separate sheet

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

   ☒ all parts.

   ☐ the parts relating to claims Nos. .

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-31
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-31
	No:	Claims	

Industrial applicability (IA)	Yes:	Claims	1-31
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item IV: Lack of unity of invention - Article 34(3) PCT

1. This international application has multiple (groups of) inventions:

   First Group of Inventions:
   Claims 1 to 13: A 3D range measurement camera with a switchable current source for performing a time of flight measurement to determine the distance to an object.

   Second Group of Inventions:
   Claims 14 to 31: A 3D range measurement camera with a controllable fan beam for performing a triangulation measurement to determine the distance to an object.

2. The reasons for the objection of lack of unity are:

2.1 From the comparison of independent claim 1 (the first group of inventions) with document D1, the following technical feature can be seen as making a contribution over this prior art (Special Technical Features, Rule 13(2) PCT) (see item V):

- The electronic circuit of each of the plurality of pixels includes a switchable current source which provides a predetermined current

From this Special Technical Feature, the objective technical problem to be solved by the first group of inventions can be seen as:

- Determining the time of flight of the light pulse reflected at the object in an alternative way

2.2 From the comparison of independent claims 14 and 27 (the second group of inventions) with document D2, the following technical features can be seen as making a contribution over this prior art (Special Technical Features, Rule 13(2) PCT) (see item V):

- Determining the scan angle of the light beam and the position of the pixels that generates pulses

From this Special Technical Features, the objective technical problem to be solved by the second group of inventions can be seen as:

- Determining the distance from the pixel to the object by using triangulation techniques

2.3 This analysis shows that the Special Technical Feature of the first group of inventions is not the same or similar as the Special Technical Feature of the second group of inventions. A comparison of the objective technical problem of the first group of inventions with the objective technical problem of the second group of inventions, both seen in the light of the description and the drawings of the present application, indicates that there is no technical correspondence between these problems nor do they show any corresponding technical effect, so that the Special Technical Feature of the second group of inventions fails to demonstrate a correspondence with the Special Technical Feature of the first group of inventions as required by Rule 13(1) and (2) PCT.

Re Item V: Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability

1. Technical Field:
Self gating photo surface for range sensing cameras.

2. State of the Art:
The following documents have been considered for the purposes of this report:

D1: US-A-4 979 816; STEVEN J. WHITE; 25 December 1990
D2: US-A-5 682 229; RICHARD J. WANGLER; 28 October 1997
D3: US-A-5 430 290; JEAN-PIERRE MERLE ET AL; 4 July 1995

Document D1 shows (the references in parentheses applying to this document) an optical range finding system including a light source (80), a light receiving section with a plurality of light sensitive pixels (90) (charge coupled device (CCD) array) and accompanying circuits (92, 94). The light receiving section consists of a photo sensor

(pixel cell 90), a voltage-to-current converter (92) and a current integrator (range cell 94). A start signal at which the light source (80) sends out a light pulse resets the receiving section. The receiving section receives the return pulse reflected by an object and generates a first signal corresponding to the integrated intensity of the return pulse. The Circuit (92, 94) produces a second signal corresponding to the time integral of the first signal. After a predetermined time a stop signal is issued and a processor (96) determines the range of the object by dividing the second signal by the first signal (see e.g. column 2, line 49 to col. 5, l. 48 and fig. 2 to 5).

Document D2 discloses a laser range camera including a CCD array. A first light transmitting means provides a start signal when transmitting a light beam and a first light receiving means provides a stop signal when receiving the reflected light signal of an object. The time of flight of this first light pulse is determined from the start and stop signals. Range measurement means comprises a second light transmitting means with a scanning fan beam of light responsive to the start and stop signals and second light receiving means (CCD array) of which the output signal (received amount of light) is indicative of the range measurement from the camera to the object (see e.g. col. 6, l. 53 to col. 7, l. 47; col. 8, l. 18 to col. 11, l. 57; claim 1 and fig. 4, 5a, 7 and 10). Document D2 further describes prior art where a charging capacitor is used to integrate a constant current between the start and stop time of a transmitted and reflected light pulse to determine its time of flight (see e.g. col. 10, l. 37-42).

Document D3 also discloses a laser range camera where a capacitor is charged by the current generated by a photo diode (see e.g. col. 4, l. 25-66 and col. 7, l. 36 to col. 8, l. 2 and fig. 7).

3. **Independent Claims:**
Claims 1, 14 (apparatus) and 27 (method)

4. **Novelty - Article 33(2) PCT**

4.1 **Independent claim 1:**
The subject-matter of independent claim 1 differs from that of document D1 in that the electronic circuit of each of the plurality of pixels includes a switchable current source which provides a predetermined current. Therefore, the subject-matter of claim 1, as far as it can be understood (see item VIII), is considered as being novel.

4.2 Independent claim 14:

The subject-matter of independent claim 14 differs from that of document D2 in that each of the photosensitive pixels of the 3D camera includes a switch that is controlled (closed) by a controller. Therefore, the subject-matter of claim 14, as far as it can be understood (see item VIII), is considered as being novel.

4.3 Independent claim 27:

The subject-matter of independent claim 27 differs from that of document D2 in that signals from a group of photosensitive pixels are sensed simultaneously. Therefore, the subject-matter of claim 27, as far as it can be understood (see item VIII), is considered as being novel.

5. Inventive Step - Article 33(3) PCT

5.1 Independent claim 1:

By using the switchable current source the objective technical problem is solved to determine the time of flight of the light pulse reflected at the object in an alternative way. Although the prior art described in document D2 uses a charging capacitor to integrate a constant current between the start and stop time of a transmitted and reflected light pulse, the skilled person has no hint to combine the teachings of documents D1 and D2. He has no reason to modify the CCD pixel cells of document D1 which generates current from the incident light. From document D2 one cannot derive if there is a charging capacitor for each pixel or only one charging capacitor for all pixels. Further, document D2 points away from its described prior art and uses an additional light transmitting and receiving section for determining the time of flight instead of a charging capacitor. Therefore, the solution presented in independent claim 1 is not known from nor rendered obvious by the cited prior art. Hence, the subject-matter of present claim 1 is considered as being inventive. The requirements of Article 33(2) and (3) PCT are fulfilled.

5.2 Independent claim 14:

By controlling the pixel switches the objective technical problem is solved to determine a distance from the pixel to the object by using triangulation. When the switches of the pixels are closed the controller makes a triangulation by determining the scan angle of the light beam and the position of the pixels that generates pulses. A 3D camera using such a triangulation process is not known from nor rendered obvious

by the cited prior art. Hence, the subject-matter of present claim 14 is considered as being inventive. The requirements of Article 33(2) and (3) PCT are also fulfilled.

5.3 **Independent claim 27:**

By simultaneously sensing signals from a group of photosensitive pixels the objective technical problem is solved to determine distances to regions of the object. It is determined which of the pixels in the group is providing a signal and the location of the pixels is used together with the scan angle to determine this distance by triangulation. This is also not known from nor rendered obvious by the cited prior art. Hence, the subject-matter of present claim 27 is considered as being inventive. The requirements of Article 33(2) and (3) PCT are also fulfilled.

5.4 **Dependent Claims 2 to 13, 15 to 26 and 28 to 31:**

The dependent claims relate to preferred embodiments of the system according to independent claims 1, 14 and 27. Therefore, the requirements of Article 33(2) and (3) PCT are also fulfilled.

6. **Industrial Applicability - Article 33(4) PCT**

The invention as claimed in claims 1 to 31 is industrially applicable in the field of range sensing cameras.

<u>Re Item VII:</u> Certain defects in the international application

1. Independent claims 1, 14 and 27 are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (documents D1, D2 respectively) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT) introduced by the wording "*characterized by*".

2. The background art disclosed in documents D1 and D2 should have been discussed in the description (Rule 5.1(a)(ii) PCT). The description has not been brought into conformity with the newly filed claims.

Re Item VIII: Certain observations

Clarity - Article 6 PCT

The present application does not satisfy the criterion set forth in Article 6 PCT, because claims 1, 3, 6, 7, 9 to 14, 21 to 23 and 25 are not clear for the following reasons:

1. **Independent claim 1:**
   Some of the features in the apparatus claim 1 relate to a method of using the apparatus rather than clearly defining the apparatus in terms of its technical features. The intended limitations are therefore not clear from this claim, contrary to the requirements of Article 6 PCT:

   "*A photo sensor that generates ...*", "*... that can be turned on or off ...*", "*... that integrates ...*" and "*... that turns ... and generates ...*".

   This should be changed in "*... for generating/integrating etc. ...*".

2. **Dependent claims 3, 6, 7, 9 to 14, 21 to 23 and 25:**
   Some of the features in the apparatus claims 3, 6, 7, 9 to 14, 21 to 23 and 25 also relate to a method of using the apparatus or are defined in terms of their function::
   - "*switches/illuminates/reflects/determines/provides/closes/controls ...*"
   - "*... said fan beam moves ...*" and "*... so that differences ... are greater/less ...*"

   The apparatus should be clearly defined in terms of its technical features.

CLAIMS

1. A semiconductor surface comprising a plurality of light sensitive pixels, wherein each pixel of said plurality of pixels comprises an electronic circuit formed on or in said semiconductor surface, said circuit comprising:

a photosensor that generates a signal responsive to light incident thereon at an output thereof;

a current integrator;

a switchable current source that can be turned on or off, which when on provides a predetermined current that flows into the integrator; and

circuitry that turns the switchable current source on at a start time and subsequently turns the source off at a stop time and generates a signal responsive to current from the current source that is integrated by the integrator between the start and stop times and wherein one of the start time and stop time is determined responsive to a signal generated by the photosensor.

2. A semiconductor surface according to claim 1 wherein said current integrator comprises a capacitor.

3. A semiconductor surface according to claim 1 or claim 2 wherein the circuitry comprises a comparator having an input connected to the output of the photosensor and an output connected to an input of the switchable current source, wherein when light incident on the photosensor has an intensity greater than a predetermined intensity, the output signal from the photosensor switches the switchable current source between on and off.

4. A semiconductor surface according to any of the preceding claims wherein the switchable current source comprises a flip-flop.

5. A semiconductor surface according to any of the preceding claims wherein the circuit is formed as a monolithic integrated circuit.

6. A semiconductor surface according to any of the preceding claims wherein the circuitry switches the switchable current source to on at the start time responsive to the signal from the photosensor.

7. A semiconductor surface according to any of claims 1-5 wherein the circuitry switches the switchable current source to off at the stop time responsive to the signal from the photosensor.

8. A 3D camera comprising a semiconductor surface according to any of the preceding claims.

9. A 3D camera comprising:

a semiconductor surface according to any of claims 1-5 or claim 7;

a light source that illuminates objects in a scene imaged with said 3D camera with at least one light pulse;

wherein for each pixel of said plurality of pixels said start time is a time at which said at least one light pulse is radiated and said stop time is a time at which light from said at least one light pulse reflected by a surface region of said objects is incident on said pixel,

and including circuitry that computes a distance between said pixel and said surface region responsive to the time lapse between the start and stop times.

10. A 3D camera comprising:

a semiconductor surface according to any of claims 1-5 or 8;

a light source controllable to illuminate at known times an object with light from a fan beam at a plurality of positions of the fan beam, each of the positions being defined by a scan angle;

wherein said start time for said plurality of pixels is a time prior to illumination of the object by the fan beam at a plurality of scan angles and wherein for each scan angle light reflected from the fan beam by a region of the object is incident on a pixel of the plurality of pixels and said stop time for the pixel is a time at which reflected light is incident on the pixel; and

including circuitry that determines from the signal responsive to the current integrated between the start and stop times and the known times a scan angle for the fan beam from which the pixel is illuminated and uses the scan angle and position of the pixel in the semiconductor surface to determine by triangulation a distance of the region from the pixel.

11. A 3D camera according to claim 10 wherein said fan beam moves between scan angles at a rate so that differences between said stop times for different pixels illuminated with reflected light from said fan beam at different scan angles are greater than a given time difference and differences between said stop times for different pixels illuminated with reflected light from said fan beam at the same scan angle are less than the given time difference.

12. A 3D camera according to claim 11 comprising a reflector that reflects light to at least one pixel in said semiconductor surface for each of said scan angles and wherein for a given scan angle, differences between said stop time for said at least one pixel and said stop times for pixels illuminated by light from said fan beam reflected by said object are less than said given time difference.

13. A 3D camera according to claim 12 and including circuitry that determines said given scan angle from the location of said at least one pixel.

14. A 3D camera for measuring distances to points on an object comprising:

a semiconductor surface comprising a plurality of light sensitive pixels wherein each pixel comprises a circuit having a photosensor, a switch and an output terminal, wherein said circuit provides a signal on said output terminal only while light is incident on said photosensor and said switch is closed; a fan beam controllable to illuminate the object from at least one position of the fan beam, which position is defined by a scan angle, so that light from said fan beam is reflected by said object to at least one of said pixels,

a controller that controls the fan beam to illuminate the object at a plurality of scan angles of the fan beam, wherein for each scan angle, while light from the fan beam illuminates the object, the controller simultaneously closes a plurality of the switches and for a pixel that generates a pulse when the pixel's switch is closed, the controller determines a distance from the pixel to the object by triangulation responsive to the scan angle and the position of the pixel in the semiconductor surface.

15. A 3D camera according to claim 14 wherein said circuits are formed in or on said semiconductor surface.

16. A 3D camera according to claim 14 or claim 15 wherein said circuits are formed as elements of a monolithic integrated circuit.

17. A 3D camera according to any of claims 14 - 16 comprising signal receiving circuitry having a plurality of inputs and wherein pixels for which said switches are simultaneously closed have said output terminals connected to different inputs of said signal receiving circuitry.

18. A 3D camera according to claim 17 wherein said signal receiving circuitry comprises an encoder.

19. A 3D camera according to claim 17 or claim 18 wherein said plurality of pixels comprises an array of pixels having rows and columns of pixels, wherein each pixel belongs to one row and one column of said array.

20. A 3D camera according to claim 19 wherein said output terminals of pixels in a same column of pixels are connected to a same input of said encoder.

21. A 3D camera according to claim 20 wherein the controller closes, substantially simultaneously, said switches of all pixels in a same single row of pixels.

22. A 3D camera according to claim 21 wherein the controller sequentially closes, row by row, the switches of all the pixels in each row of pixels.

23. A 3D camera according to any of claims 19 - 22 wherein columns of said semiconductor surface are parallel to the plane of said fan beam for all positions of said fan beam at which said fan beam illuminates said object.

24. A 3D camera according to any of claims 14 - 23 wherein an output of said photosensor is connected to a contact terminal of said switch.

25. A 3D camera according to any of claims 14 - 23 wherein said circuit comprises a comparator having a first input connected to said photosensor, a second input biased with a

reference voltage and an output and wherein when light having an intensity greater than a predetermined intensity is incident on said photosensor, voltage on the first input rises above the reference voltage and the comparator generates an output signal.

26. A 3D camera according to claim 25 wherein said output of said comparator is connected to a contact terminal of said switch.

27. A method of measuring distances to regions of an object comprising:

providing a semiconductor surface having a plurality of light sensitive pixels, each of which provides an output signal responsive to light thereon only while illuminated with the light;

illuminating said object with light from a fan beam of light having a position defined by a scan angle so that light from the fan beam is reflected by the object to at least one of said plurality of pixels;

simultaneously sensing signals from a group of pixels in the semiconductor surface to determine which of the pixels in the group is providing a signal;

determining the scan angle for the pixels in the group of pixels;

using locations of pixels that provide signals and said determined scan angle to determine distances to regions of said object.

28. A method according to claim 27 wherein said plurality of pixels in the semiconductor surface is arranged in a rectangular array of rows and columns pixels.

29. A method according to claim 28 wherein the group of pixels comprises all pixels in a same row of pixels.

30. A method according to claim 29 and comprising sensing signals from pixels in the semiconductor surface in a plurality of rows of pixels sequentially, row by row.

31. A method according to any of claims 28 - 30 comprising providing a signal sensing means and wherein sensing signals comprises sensing signals from all pixels in a column of pixels on a same input of said sensing means.

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

FENSTER & COMPANY PATENT
ATTORNEYS, LTD
P.O.Box 10256
Petach Tikva 49002
ISRAEL

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

	Date of mailing *(day/month/year)* 09.03.2001	
Applicant's or agent's file reference 001/00620	**IMPORTANT NOTIFICATION**	
International application No. PCT/IL98/00611	International filing date *(day/month/year)* 16/12/1998	Priority date *(day/month/year)* 16/12/1998
Applicant 3DV SYSTEMS, LTD. et al.		

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

   The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

   Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

   For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/ European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Marnell, J Tel.+49 89 2399-2557

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 001/00620	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/IL98/00611	International filing date *(day/month/year)* 16/12/1998	Priority date *(day/month/year)* 16/12/1998
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Applicant 3DV SYSTEMS, LTD. et al.		

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   VII ☒ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
28/02/2000	09.03.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Springer, O Telephone No. +49 89 2399 2619

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:

Description, pages:

1-19	as originally filed	

Claims, No.:

1-31	with telefax of	20/02/2001

Drawings, sheets:

1/3-3/3	as originally filed	

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
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- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
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☐ the description,	pages:	
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IV. Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

   ☐ restricted the claims.

   ☐ paid additional fees.

   ☐ paid additional fees under protest.

   ☐ neither restricted nor paid additional fees.

2. ☒ This Authority found that the requirement of unity of invention is not complied and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

   ☐ complied with.

   ☒ not complied with for the following reasons:
   see separate sheet

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

   ☒ all parts.

   ☐ the parts relating to claims Nos. .

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-31
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-31
	No:	Claims	

Industrial applicability (IA)	Yes:	Claims	1-31
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item IV: Lack of unity of invention - Article 34(3) PCT

1. This international application has multiple (groups of) inventions:

First Group of Inventions:

Claims 1 to 13: A 3D range measurement camera with a switchable current source for performing a time of flight measurement to determine the distance to an object.

Second Group of Inventions:

Claims 14 to 31: A 3D range measurement camera with a controllable fan beam for performing a triangulation measurement to determine the distance to an object.

2. The reasons for the objection of lack of unity are:

2.1 From the comparison of independent claim 1 (the first group of inventions) with document D1, the following technical feature can be seen as making a contribution over this prior art (Special Technical Features, Rule 13(2) PCT) (see item V):

- The electronic circuit of each of the plurality of pixels includes a switchable current source which provides a predetermined current

From this Special Technical Feature, the objective technical problem to be solved by the first group of inventions can be seen as:

- Determining the time of flight of the light pulse reflected at the object in an alternative way

2.2 From the comparison of independent claims 14 and 27 (the second group of inventions) with document D2, the following technical features can be seen as making a contribution over this prior art (Special Technical Features, Rule 13(2) PCT) (see item V):

- Determining the scan angle of the light beam and the position of the pixels that generates pulses

From this Special Technical Features, the objective technical problem to be solved by the second group of inventions can be seen as:

- Determining the distance from the pixel to the object by using triangulation techniques

2.3 This analysis shows that the Special Technical Feature of the first group of inventions is not the same or similar as the Special Technical Feature of the second group of inventions. A comparison of the objective technical problem of the first group of inventions with the objective technical problem of the second group of inventions, both seen in the light of the description and the drawings of the present application, indicates that there is no technical correspondence between these problems nor do they show any corresponding technical effect, so that the Special Technical Feature of the second group of inventions fails to demonstrate a correspondence with the Special Technical Feature of the first group of inventions as required by Rule 13(1) and (2) PCT.

<u>Re Item V:</u> Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability

1. Technical Field:

Self gating photo surface for range sensing cameras.

2. State of the Art:

The following documents have been considered for the purposes of this report:

D1: US-A-4 979 816; STEVEN J. WHITE; 25 December 1990
D2: US-A-5 682 229; RICHARD J. WANGLER; 28 October 1997
D3: US-A-5 430 290; JEAN-PIERRE MERLE ET AL; 4 July 1995

Document D1 shows (the references in parentheses applying to this document) an optical range finding system including a light source (80), a light receiving section with a plurality of light sensitive pixels (90) (charge coupled device (CCD) array) and accompanying circuits (92, 94). The light receiving section consists of a photo sensor

(pixel cell 90), a voltage-to-current converter (92) and a current integrator (range cell 94). A start signal at which the light source (80) sends out a light pulse resets the receiving section. The receiving section receives the return pulse reflected by an object and generates a first signal corresponding to the integrated intensity of the return pulse. The Circuit (92, 94) produces a second signal corresponding to the time integral of the first signal. After a predetermined time a stop signal is issued and a processor (96) determines the range of the object by dividing the second signal by the first signal (see e.g. column 2, line 49 to col. 5, l. 48 and fig. 2 to 5).

Document D2 discloses a laser range camera including a CCD array. A first light transmitting means provides a start signal when transmitting a light beam and a first light receiving means provides a stop signal when receiving the reflected light signal of an object. The time of flight of this first light pulse is determined from the start and stop signals. Range measurement means comprises a second light transmitting means with a scanning fan beam of light responsive to the start and stop signals and second light receiving means (CCD array) of which the output signal (received amount of light) is indicative of the range measurement from the camera to the object (see e.g. col. 6, l. 53 to col. 7, l. 47; col. 8, l. 18 to col. 11, l. 57; claim 1 and fig. 4, 5a, 7 and 10). Document D2 further describes prior art where a charging capacitor is used to integrate a constant current between the start and stop time of a transmitted and reflected light pulse to determine its time of flight (see e.g. col. 10, l. 37-42).

Document D3 also discloses a laser range camera where a capacitor is charged by the current generated by a photo diode (see e.g. col. 4, l. 25-66 and col. 7, l. 36 to col. 8, l. 2 and fig. 7).

3. Independent Claims:

Claims 1, 14 (apparatus) and 27 (method)

4. Novelty - Article 33(2) PCT

4.1 Independent claim 1:

The subject-matter of independent claim 1 differs from that of document D1 in that the electronic circuit of each of the plurality of pixels includes a switchable current source which provides a predetermined current. Therefore, the subject-matter of claim 1, as far as it can be understood (see item VIII), is considered as being novel.

4.2 Independent claim 14:

The subject-matter of independent claim 14 differs from that of document D2 in that each of the photosensitive pixels of the 3D camera includes a switch that is controlled (closed) by a controller. Therefore, the subject-matter of claim 14, as far as it can be understood (see item VIII), is considered as being novel.

4.3 Independent claim 27:

The subject-matter of independent claim 27 differs from that of document D2 in that signals from a group of photosensitive pixels are sensed simultaneously. Therefore, the subject-matter of claim 27, as far as it can be understood (see item VIII), is considered as being novel.

5. Inventive Step - Article 33(3) PCT

5.1 Independent claim 1:

By using the switchable current source the objective technical problem is solved to determine the time of flight of the light pulse reflected at the object in an alternative way. Although the prior art described in document D2 uses a charging capacitor to integrate a constant current between the start and stop time of a transmitted and reflected light pulse, the skilled person has no hint to combine the teachings of documents D1 and D2. He has no reason to modify the CCD pixel cells of document D1 which generates current from the incident light. From document D2 one cannot derive if there is a charging capacitor for each pixel or only one charging capacitor for all pixels. Further, document D2 points away from its described prior art and uses an additional light transmitting and receiving section for determining the time of flight instead of a charging capacitor. Therefore, the solution presented in independent claim 1 is not known from nor rendered obvious by the cited prior art. Hence, the subject-matter of present claim 1 is considered as being inventive. The requirements of Article 33(2) and (3) PCT are fulfilled.

5.2 Independent claim 14:

By controlling the pixel switches the objective technical problem is solved to determine a distance from the pixel to the object by using triangulation. When the switches of the pixels are closed the controller makes a triangulation by determining the scan angle of the light beam and the position of the pixels that generates pulses. A 3D camera using such a triangulation process is not known from nor rendered obvious

by the cited prior art. Hence, the subject-matter of present claim 14 is considered as being inventive. The requirements of Article 33(2) and (3) PCT are also fulfilled.

5.3 Independent claim 27:

By simultaneously sensing signals from a group of photosensitive pixels the objective technical problem is solved to determine distances to regions of the object. It is determined which of the pixels in the group is providing a signal and the location of the pixels is used together with the scan angle to determine this distance by triangulation. This is also not known from nor rendered obvious by the cited prior art. Hence, the subject-matter of present claim 27 is considered as being inventive. The requirements of Article 33(2) and (3) PCT are also fulfilled.

5.4 Dependent Claims 2 to 13, 15 to 26 and 28 to 31:

The dependent claims relate to preferred embodiments of the system according to independent claims 1, 14 and 27. Therefore, the requirements of Article 33(2) and (3) PCT are also fulfilled.

6. Industrial Applicability - Article 33(4) PCT

The invention as claimed in claims 1 to 31 is industrially applicable in the field of range sensing cameras.

<u>Re Item VII:</u> Certain defects in the international application

1. Independent claims 1, 14 and 27 are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (documents D1, D2 respectively) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT) introduced by the wording "*characterized by*".

2. The background art disclosed in documents D1 and D2 should have been discussed in the description (Rule 5.1(a)(ii) PCT). The description has not been brought into conformity with the newly filed claims.

Re Item VIII: Certain observations

Clarity - Article 6 PCT

The present application does not satisfy the criterion set forth in Article 6 PCT, because claims 1, 3, 6, 7, 9 to 14, 21 to 23 and 25 are not clear for the following reasons:

1. **Independent claim 1:**
   Some of the features in the apparatus claim 1 relate to a method of using the apparatus rather than clearly defining the apparatus in terms of its technical features. The intended limitations are therefore not clear from this claim, contrary to the requirements of Article 6 PCT:

   "*A photo sensor that generates ...*", "*... that can be turned on or off ...*", "*... that integrates ...*" and "*... that turns ... and generates ...*".

   This should be changed in "*... for generating/integrating etc. ...*".

2. **Dependent claims 3, 6, 7, 9 to 14, 21 to 23 and 25:**
   Some of the features in the apparatus claims 3, 6, 7, 9 to 14, 21 to 23 and 25 also relate to a method of using the apparatus or are defined in terms of their function::
   - "*switches/illuminates/reflects/determines/provides/closes/controls ...*"
   - "*... said fan beam moves ...*" and "*... so that differences ... are greater/less ...*"

   The apparatus should be clearly defined in terms of its technical features.

PCT

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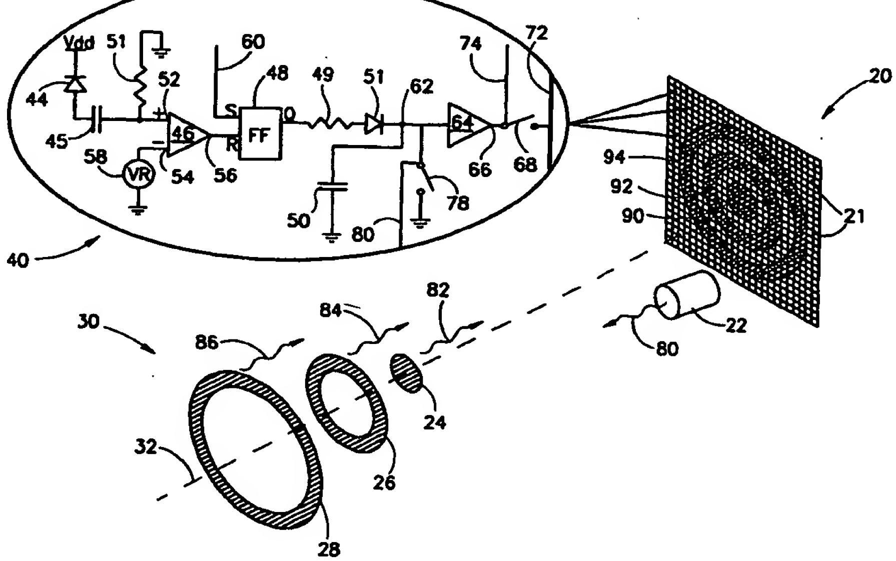


(57) Abstract

A semiconductor surface is provided comprising a plurality of light sensitive pixels wherein each pixel of the plurality of pixels comprises an electronic circuit formed on or in the semiconductor surface, the circuit comprising: a photosensor that generates a signal responsive to light incident thereon at an output thereof; and circuitry that provides a signal responsive to a time lapse between a first time responsive to said signal and a reference time. There is also provided a 3D camera incorporating the semiconductor surface.

SELF GATING PHOTOSURFACE

FIELD OF THE INVENTION

The invention relates to cameras that provide measurements of distances to objects and parts of objects that they image and in particular to integrating functions of such cameras on a single chip.

BACKGROUND OF THE INVENTION

Three dimensional optical imaging systems, hereinafter referred to as "3D cameras", that are capable of providing distance measurements to objects and points on objects that they image, are used for many different applications. Among these applications are profile inspection of manufactured goods, CAD verification, robot vision, geographic surveying and imaging objects selectively as a function of distance.

Some 3D cameras use a time of flight technique to measure distances to an object in a scene. A 3D camera of this type usually comprises a light source, such as a laser, which is pulsed or shuttered to illuminate a scene being imaged with light pulses and a gated imaging system for imaging light from the light pulses that is reflected from objects in the scene. The gated imaging system comprises a camera, such as a CCD or CMOS camera, or an IR camera, having a photosensitive surface, hereinafter referred to as a "photosurface", and a gating means for gating the camera open and closed, such as an electro-optical shutter or a gated image intensifier. The reflected light is registered on pixels of the photosurface of the camera only if it reaches the camera when the camera is gated open.

To image a scene and determine distances from the camera to objects in the scene, the scene is generally illuminated with a train of light pulses radiated from the light source. For each radiated light pulse in the train, following an accurately determined delay from the time that the light pulse is radiated, the camera is gated open for a limited period of time hereinafter referred to as a "gate". Light from the light pulse that is reflected from an object in the scene is imaged on the photosurface of the camera if it reaches the camera during the gate. Since the time elapsed between radiating a light pulse and the gate that follows it is known, the time it took imaged light to travel from the light source to the reflecting object in the scene and back to the camera is known. The time elapsed is used to determine the distance to the object.

Some 3D cameras use a geometrical relationship between an incident beam of light that illuminates the surface of an object and light reflected from the incident beam by the surface to determine distances to the object. Generally, at any one time, the incident beam illuminates a limited surface region of the object and distances to the object are measured only for points of

the object in the limited surface region. To measure distance to points in different surface regions the position of the beam is changed. Generally, "geometrical" measurements of distances to an object are made using a triangulation technique.

A common "geometrical" method of 3D imaging is active triangulation. In active triangulation, generally, a thin fan beam of laser light illuminates the surface of an object along a thin stripe on the surface. Light reflected from the illuminated stripe is incident on pixels in an appropriate photosurface. Each illuminated pixel in the photosurface is illuminated by light reflected from a different spot on the stripe. The position of an illuminated pixel in the photosurface and the angle, hereinafter the "scan angle", that the plane of the fan beam makes with a reference coordinate system is sufficient to determine three spatial coordinates for the spot on the stripe that reflects light to the pixel. To produce a 3D map of the surface of the object, the scan angle is incremented so that the fan beam scans the surface of the object, illuminating it successively along different closely spaced stripes on the surface. For each of these closely spaced stripes, the spatial coordinates of spots on the stripes corresponding to illuminated pixels are calculated.

3D cameras using time of flight and variations of time of flight techniques to determine distances to an object are described in PCT application PCT/IL98/00476 by some of the inventors of the present application, which PCT application is incorporated herein by reference. 3D cameras using substantially "geometrical" methods for measuring distances to an object are described in PCT application PCT/IL97/00370, also by some of the inventors of the present application, which PCT application is incorporated herein by reference.

SUMMARY OF THE INVENTION

An aspect of a preferred embodiment of the present invention relates to providing a photosurface useable in a 3D camera, which photosurface incorporates gating apparatus for the 3D camera that automatically gates pixels in the photosurface on or off in response to light incident on the pixels.

Another aspect of a preferred embodiment of the present invention relates to providing a photosurface comprising a plurality of pixels, in which each pixel of the plurality of pixels provides information responsive to the duration of a time lapse between a reference time and a time when light is incident on the pixel.

In some preferred embodiments of the present invention the pixels are gated on at the reference time and gated off at the time when light is incident on the pixels.

In some preferred embodiments of the present invention the pixels are gated on when light is incident on the pixels and gated off at the reference time.

Another aspect of some preferred embodiments of the present invention relates to providing a 3D camera that uses a photosurface, in accordance with a preferred embodiment of the present invention, to measure distances to an object using a time of flight technique.

Another aspect of some preferred embodiments of the present invention relates to providing a 3D camera that uses a photosurface, in accordance with a preferred embodiment of the present invention, to measure distances to an object using a triangulation technique.

In accordance with an aspect of a preferred embodiment of the present invention, each pixel in the photosurface includes its own pixel circuit for gating the pixel on or off. The pixel circuit is controllable to gate the pixel on at a reference time, hereinafter referred to as "start time". Once gated on, the pixel circuit subsequently gates the pixel off at a time, hereinafter referred to as "stop time", at which time light to which the pixel is sensitive is incident on the pixel. In some preferred embodiments of the present invention the pixel circuit is gated on when light is incident on the pixel and gated off at a subsequent reference time. In such preferred embodiments of the present invention the start time is the time at which light is incident on the pixel and the stop time is the reference time.

In some preferred embodiments of the present invention, a time lapse between a start time and a stop time of a pixel is determined from an amount of charge accumulated between start time and stop time by a charge integrating means, such as a capacitor, in the pixel circuit.

In a photosurface in accordance with a preferred embodiment of the present invention, the pixel circuit of each pixel of the photosurface comprises a photosensor, a comparator, a flip-flop and a storage capacitor.

When an output of the flip-flop is turned on, current from a suitable current source flows into the storage capacitor. When the output is turned off no current flows into the storage capacitor. The output of the flip-flop is controllable to be turned on by an appropriate signal from a controller connected to a first input of the flip-flop. A second input of the flip-flop is connected to an output of the comparator. The output of the comparator has an on and off state. If the output of the flip-flop is on when the output of the comparator switches from off to on, i.e. when the output of the comparator "turns on", the output of the flip-flop turns off.

Current from the photosensor, hereinafter referred to as "photocurrent", controls when the output of the comparator turns on and thereby when the output of the flip-flop turns off and the storage capacitor stops integrating current. The photosensor is preferably connected to a

positive input of the comparator. A voltage source that provides a reference voltage is preferably connected to a negative input of the comparator. When no current is flowing in the photosensor, voltage of the positive input is below the reference voltage. When light to which the photosensor is sensitive is incident on the photosensor with sufficient intensity, current from the photosensor raises the voltage of the positive input above the reference voltage. The crossing of the photosensor input voltage from below to above the reference voltage turns on the output of the comparator. This in turn, turns off the output of the flip-flop and stops current flowing into the storage capacitor from the current source.

Variations of the above noted connections between the photosensor, voltage source and comparator are possible. For example, the reference voltage can be negative as well as positive and the flip-flop can be turned off when voltage of the photosensor input crosses from above to below a reference voltage. Such variations will occur to persons of the art and can be advantageous.

Start and stop times of the pixel are respectively, the time at which the flip-flop turns on and the storage capacitor starts integrating current and the time that the flip-flop turns off and the storage capacitor stops integrating current. The charge accumulated by the storage capacitor between the start and stop times is a function of the time lapse between the start and stop times. The charge accumulated on the storage capacitor is sensed and registered using methods known in the art and then used to determine the time lapse.

In a 3D camera that uses a time of flight technique to measure distances to an object, in accordance with a preferred embodiment of the present invention, elapsed time between a start time and a stop time of a pixel is used to measure the time it takes a pulse of light to travel from a light source to the object and back to the pixel.

In a 3 D camera that uses a triangulation technique to measure distances to an object, in accordance with a preferred embodiment of the present invention, elapsed time between a start time and a stop time of a pixel indicates the position of a light beam that illuminates the object from which light is reflected by the object to the pixel.

In some photosurfaces, in accordance with preferred embodiments of the present invention, both the start times and the stop times of the pixel circuit are controlled by light incident on the pixel. In a photosurface of this type, in accordance with a preferred embodiment of the present invention, a pixel circuit comprises a photosensor connected to a first input of a comparator. A second input of the comparator is connected to a voltage source that maintains the second input at a reference voltage. When light of having intensity greater than a certain

threshold intensity is incident on the photosensor, voltage on the positive input of the comparator rises above the reference voltage and the pixel circuit is gated on. When the intensity of the light drops below the threshold intensity, the pixel circuit is gated off. In some preferred embodiments of the present invention, a 3D camera that incorporates a photosurface of this type is used to measure distances to an object using triangulation.

Preferably, the pixels are packed on the photosensitive surface with a pitch less than 50 microns. More preferably the pixels are packed with a pitch less than 30 microns. Preferably, the photosurface is produced using CMOS technology. Using CMOS technology, light sensitive photosurfaces comprising arrays of pixels suitable for visual imaging can be produced, wherein each pixel of the photosurface contains a pixel circuit having a photosensor, such as a photo-diode, and electronic switching, control and logic elements. For example, US patent 5,345,266 describes a pixel comprising a photodiode and a transistor. Peter Denyer in a talk given at the 1996 SSCTC Workshop On CMOS Imaging Technology, Feb 7, 1996, described a pixel comprising electronic elements that is on the order of 12 microns on a side and in which the photodiode occupies 60% the pixel area. In some preferred embodiments of the present invention pixel circuits are formed as elements of a monolithic multilayer circuit in which switching control and/or logic components of the pixel circuits are in levels of the monolithic circuit below a surface level on which the photosensors are located.

There is thus provided, in accordance with a preferred embodiment of the present invention a semiconductor surface comprising a plurality of light sensitive pixels, wherein each pixel of the plurality of pixels comprises an electronic circuit formed on or in the semiconductor surface, the circuit comprising: a photosensor that generates a signal responsive to light incident thereon at an output thereof; and circuitry that provides a signal responsive to a time lapse between a first time responsive to the signal and a reference time.

Preferably, the circuitry comprises a current integrator that integrates a current during the time lapse. Preferably, the current integrator comprises a capacitor.

Alternatively or additionally, the circuitry comprises a switchable source having on and off states, wherein when the switchable source is in the on state the integrator integrates current and wherein when the switchable source is in the off state the integrator does not integrate current.

Preferably, the circuitry comprises a comparator having an output connected to an input of the switchable source, the photosensor output being connected to an input of the comparator

such that when light incident on the photosensor has an intensity greater than a predetermined intensity the switchable source changes states.

Alternatively or additionally, the circuitry preferably switches the switchable source to the off state, at the first time, responsive to the signal from the photosensor.

Alternatively, the circuitry switches the switchable source to the on state, at the first time, responsive to the signal from the photosensor.

In some preferred embodiments of the present invention the switchable source is a flip-flop.

In some preferred embodiments of the present invention the circuit is formed as a monolithic integrated circuit.

There is further provide a 3D camera comprising a semiconductor surface according to any preferred embodiment of the present invention.

According to some preferred embodiments of the present invention the 3D camera comprises: a light source that illuminates objects in a scene imaged with the 3D camera with at least one light pulse; wherein for each pixel of the plurality of pixels the reference time is a time at which the at least one light pulse is radiated and the first time is a time at which light from the at least one light pulse reflected by a surface region of the objects is incident on the pixel, and including circuitry that computes the distance between the pixel and the surface region responsive to the time lapse.

According to some preferred embodiments of the present invention the 3D camera comprises a fan beam wherein the position of the fan beam is defined by a scan angle. Preferably, the fan beam illuminates an object at a plurality of different scan angles and the photosensor signals are generated responsive to light reflected by the object from the fan beam to the photosensors and wherein the fan beam moves between scan angles at a rate so that differences between the first times for different pixels illuminated with reflected light from the fan beam at different scan angles are greater than a given time difference and differences between the first times for different pixels illuminated with reflected light from the fan beam at the same scan angle are less than the given time difference.

Preferably, the time at which the fan beam illuminates the object at each of the plurality of scan angles is known.

Alternatively or additionally, the 3D camera preferably comprises a reflector that reflects light to at least one pixel in the semiconductor surface for each of the scan angles and wherein for a given scan angle differences between the first time for the at least one pixel and

the first times for pixels illuminated by light from the fan beam reflected by the object are less than the given time difference. Preferably, the 3D camera comprises circuitry that determines the given scan angle from the location of the at least one pixel.

According to some preferred embodiments of the present invention, the reference time is the same for all pixels of the plurality of the pixels.

According to other preferred embodiments of the present invention, the reference time is different for at least two pixels of the plurality of pixels.

There is further provided, in accordance with a preferred embodiment of the present invention, a 3D camera for measuring distances to points on an object comprising: a semiconductor surface comprising a plurality of light sensitive pixels wherein each pixel comprises a circuit having a photosensor, a switch and an output terminal, wherein the circuit provides a signal on the output terminal only when light is incident on the photosensor and the switch is closed; and a fan beam that illuminates the object for at least one position of the fan beam so that light from the fan beam is reflected by the object to at least one of the pixels, wherein for each position of the fan beam, a plurality of the switches are closed simultaneously.

Preferably the circuits are formed in or on the semiconductor surface. Alternatively or additionally, the circuits are preferably formed as elements of a monolithic integrated circuit.

Alternatively or additionally, the 3D camera comprises signal receiving circuitry having a plurality of inputs and wherein pixels for which the switches are simultaneously closed have the output terminals connected to different inputs of the signal receiving circuitry. Preferably, the plurality of pixels comprises an array of pixels having rows and columns of pixels, wherein each pixel belongs to one row and one column of the array. Preferably, the output terminals of pixels in a same column of pixels are connected to a same input of the encoder.

Preferably, the switches of all pixels in a same row of pixels are simultaneously closed. Preferably, the switches of pixels in the semiconductor surface are sequentially closed, row by row.

Alternatively or additionally, rows of the semiconductor surface are parallel to the plane of the fan beam for all positions of the fan beam at which the fan beam illuminates the object.

According to some preferred embodiments of the present invention, an output of the photosensor is connected to a contact terminal of the switch.

According to some preferred embodiments of the present invention the circuit comprises a comparator having an input connected to the photosensor wherein, when light having an intensity greater than a predetermined intensity is incident on the photosensor, a signal is generated on an output of the comparator. Preferably, the output of the comparator is connected to a contact terminal of the switch.

According to some preferred embodiments of the present invention the signal receiving circuitry comprises an encoder.

There is further provided, in accordance with a preferred embodiment of the present invention a method of measuring distances to regions on an object comprising: providing a semiconductor surface having a first plurality of light sensitive pixels; illuminating the object with light from a fan beam of light having a position defined by a scan angle; sensing signals from pixels on the semiconductor surface that are illuminated with light reflected from the fan beam by the object by simultaneously interrogating a second plurality of pixels comprised in the first plurality of pixels; determining a scan angle for pixels that provide signals; using locations of pixels that provide signals and the determined scan angles to determine distances to regions of the object.

Preferably, the first plurality of pixels are arranged in a rectangular array of rows and columns pixels. Preferably, all pixels in a row of pixels are interrogated simultaneously. Pixels in the first plurality of pixels are preferably interrogated sequentially, row by row.

Additionally or alternatively the method comprises providing a signal sensing means and wherein sensing signals comprises sensing signals from all pixels in a column of pixels on a same input of the sensing means.

The invention will be more clearly understood by reference to the following description of preferred embodiments thereof read in conjunction with the figures attached hereto. In the figures identical structures, elements or parts which appear in more than one figure are labeled with the same numeral in all the figures in which they appear. The figures are listed below and:

BRIEF DESCRIPTION OF FIGURES

Figs. 1A and 1B show a schematic of a self triggering photosurface and a circuit diagram of its pixels and schematically illustrates how the photosurface is used to determine distances to objects in a scene using time of flight, in accordance with a preferred embodiment of the present invention;

Fig. 2 schematically shows a 3D camera, comprising the same self triggering photosurface shown in Fig. 1A, that is used to determine distances to an object using triangulation, in accordance with a preferred embodiment of the present invention; and

Fig. 3 schematically shows a different photosurface and a 3D camera for imaging an object using triangulation, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1A schematically shows a photosurface 20, in accordance with a preferred embodiment of the present invention. Photosurface 20 comprises pixels 21, each of which preferably has a pixel circuit 40 shown schematically and greatly magnified. The operation of circuit 40 is controlled and monitored by an appropriate controller (not shown).

Photosurface 20 is shown in Fig. 1A being used with a pulsed laser 22 to determine distances to objects 24, 26 and 28 in a scene 30, in accordance with a preferred embodiment of the present invention. Photosurface 20 and laser 22 are parts of a 3D camera that operates as a range finding "time of flight" camera, in accordance with a preferred embodiment of the present invention. Only the parts of the 3D camera that are relevant to the discussion are shown. Preferably, photosurface 20 is appropriately shielded by a filter (not shown) that transmits substantially only light having a wavelength the same as a wavelength of light radiated by laser 22.

For ease and clarity of presentation, elements in Fig. 3 are not shown to scale and for simplicity of exposition each of objects 24, 26 and 28 in scene 30 are planar and rotationally symmetric about the optic axis 32 of the 3D camera. All regions of an object 24, 26 or 28 are equidistant from photosurface 20. Each of objects 24, 26 and 28 is located at a different distance from photosurface 20.

The 3D camera measures distance to objects 24, 26 and 28 that are imaged on photosurface 20 by determining how long it takes light pulses to travel from laser 22 to each of objects 24, 26 and 28 and back to photosurface 20. However, the invention is applicable to measurement of more complicated surfaces

Pixel circuit 40 preferably comprises a photosensor 44, preferably back biased with a voltage V_{dd}, a comparator 46, a flip-flop 48 and a storage capacitor 50. Photosensor 44 is preferably capacitively coupled with a capacitor 45 to a positive input 52 of comparator 46. Capacitive coupling eliminates DC input to input 52 which is typically generated by relatively constant background light. A voltage source 58 is preferably connected to a negative input 54 of comparator 46 and maintains input 54 at a desired reference voltage V_R. Preferably, input

52 is connected to ground through a bleeding resistor 51 having appropriate resistance. Output 56 of comparator 46 is connected to a reset input "R" of flip-flop 48 and a flip-flop control line 60 connects a set input "S" of flip-flop 48 to the controller. An output Q of flip-flop 48 is connected in series with a current limiting resistor 49 and a diode 51 to storage capacitor 50 at a node 62. Node 62 is connected to a buffer amplifier 64 having an output 66 connected via an address switch 68 to a readout buss 72. Address switch 68 is controlled by the controller, to which it is connected via address control line 74. A reset switch 78, when closed, discharges any charge accumulated on storage capacitor 50. Reset switch 78 is closed and opened by signals from the controller transmitted over a reset control line 80.

When output Q of flip-flop 48 is on, current flows from output Q into capacitor 50 and charge accumulates on capacitor 50 at a rate determined substantially by the resistance of limiting resistor 49 and the capacitance of storage capacitor 50. When output Q is off, no current flows into capacitor 62 and diode 51 prevents accumulated charge on storage capacitor 50 from discharging back through flip-flop 48. Output Q of flip-flop 48 is turned on when set input S of flip-flop 48 receives a "set" signal from the controller. Output Q of flip-flop 48 is turned off when output 56 of comparator 46 turns on thereby sending a "reset" signal to input R of flip-flop 48.

Photocurrent in photosensor 44 controls when output 56 of comparator 46 turns on. As long as there is substantially no photocurrent in photosensor 44, or photocurrent in photosensor 44 is below a certain threshold current, voltage at input 52 is below V_R and output 56 of comparator 46 is off. If light to which photosensor 44 is sensitive is incident on photosensor 44 with sufficient intensity to generate a photocurrent in photosensor 44 that is above the threshold current, the voltage at input 52 exceeds V_R and comparator output 56 is on.

Charge is accumulated on storage capacitor 50 beginning from a start time at which output Q of flip-flop 48 is turned on by a set signal from the controller. Charge stops accumulating on storage capacitor 50 at a stop time at which output Q of flip flop 48 is turned off by a reset signal from output 56 of comparator 46, which reset signal is generated when light of sufficient intensity is incident on photosensor 44. Charge accumulated on storage capacitor 50 is therefore a function of the time lapse between the start time and the stop time.

Preferably, the controller operates all flip-flops 48 of pixels 21 in photosurface 20 so that all flip-flops 48 turn on together. In some preferred embodiments of the present invention this is achieved by connecting all flip-flop control lines 60 together so that a single set signal from the controller turns all flip-flops 48 on. In other preferred embodiments of the present

invention, pixels 21 are grouped into pixel groups. Flip-flop control lines 60 to all flip-flops 48 in a same pixel group are connected together and a single set signal to a pixel group from the controller turns on all pixels 21 in the group substantially simultaneously. Set signals are sent to different pixel groups with appropriate delays so that pixel groups at different distances from the controller receive set signals at substantially the same time.

To measure distances to objects 24, 26 and 28, at a time $t = 0$, after storage capacitors 50 of pixels 21 have been reset by closing and opening reset switch 78, laser 22 radiates a light pulse, represented by wavy arrow 80, to illuminate scene 30. At the same time a set signal, or signals, (depending upon the way flip–flop control lines 60 are wired) from the controller to set inputs S of flip-flops 48 turns on flip-flop outputs Q of, preferably, all pixels 21. As a result, storage capacitors 50 of all pixels 21 in photosurface 20 begin charging from currents flowing from their respective flip-flops 48 at substantially the same time $t = 0$.

Each of objects 24, 26 and 28 reflects light from radiated light pulse 80 towards photosurface 20 in reflected light pulses represented by wavy arrows 82, 84 and 86 respectively. Reflected light pulses 82, 84 and 86 are focused by collecting optics (not shown) so as to form images 90, 92 and 94 respectively of objects 24, 26 and 28 on photosurface 20.

Image 90 of object 24 is formed at a time $t_{24} = D_{24}/c$ where D_{24} is the sum of the distance from light source 22 to object 24 and the distance from object 22 to photosurface 20 and c is the speed of light. At time t_{24}, light from reflected light pulse 82 is incident on each photosensor 44 in a pixel 21 covered by image 90. In photosensor 44 of each of pixels 21 in image 90, the incident light generates a photocurrent that causes input 52 of comparator 46 of the pixel to rise above reference voltage V_R. As a result, output 56 of comparator 46 turns on and generates a reset signal at reset input R that turns output Q of flip-flop 48 off and stops current from flowing into storage capacitor 50 of the pixel. Thus, at time t_{24}, capacitors 50 in all pixels 21 in image 90 stop charging and the amount of charge accumulated on each storage capacitor 50 of pixels 21 is a function of t_{24}. The charge on each capacitor 50 of pixels 21 in image 90 can therefore be used, in accordance with a preferred embodiment of the present invention, to measure the distance to object 24.

Similarly, image 92 of object 26 is formed at a time $t_{26} = D_{26}/c$ and image 44 is formed at a time $t_{28} = D_{28}/c$ where D_{26} and D_{28} are the distances of objects 26 and 28 respectively from photosurface 20. Charges on storage capacitors in pixels 21 covered by

images 92 and 44 are functions of t_{26} and t_{28} respectively and can be used to determine the distances to each of objects 26 and 28.

The lengths of time during which storage capacitors 50 of pixels 21 in images 90, 92 and 94 integrate current from their respective flip-flops 48 are shown schematically in Fig. 1B by the length of bars 100, 102 and 104 respectively shown in a bar graph 106. Bars 100, 102 and 104 are shown extending from time t = 0 to times t24, t26 and t28 respectively.

Following exposure of photosurface 20 to reflected light pulses 82, 84 and 86, the amount of charge on storage capacitor 50 of each pixel 21 is read out. This is accomplished by turning on address switch 68 of the pixel and sensing and registering the charge deposited on readout buss 72 by buffer amplifier 64 of the pixel. The sensed charge is processed using methods known in the art to determine the time when storage capacitor 50 of the pixel 21 stopped charging and the distance from the pixel of the object imaged on the pixel.

In some preferred embodiments of the present invention a train of light pulses 80 is radiated to illuminate objects 24, 26 and 28. A frame of photosurface 20 is grabbed and charges on storage capacitors 50 read following the last light pulse 80 in the train of light pulses. Storage capacitors 50 of all pixels 21 are reset at the beginning of the train of pulses 80 and subsequently, at the time that each pulse 80 of the train of pulses is radiated, a set signal is transmitted to all flip flops 48. The charges on storage capacitors 50 that are used to determine distances to objects 24, 26 and 28 are the sums of charges accumulated for each pulse 80 in the train of light pulses. By using a train of light pulses instead of a single light pulse, random error in distance measurements to objects 24, 26 and 28 are reduced.

In some preferred embodiments of the present invention, in order to determine if background light triggers comparator 46, photosurface 20 is exposed to scene 30 without illuminating scene 30 with light from laser 22. In the event that background illumination triggers comparator 46, the magnitude of reference voltage VR is adjusted accordingly.

Fig. 2 shows a schematic of a 3D triangulation camera system 120 comprising photosurface 20 shown in Fig. 1A, in accordance with a preferred embodiment of the present invention. 3D camera 120 is shown imaging an object 122 in order to determine distances to points on object 122, in accordance with a preferred embodiment of the present invention. Only parts of the 3D camera that are relevant to the discussion are shown and sizes of the parts and other elements shown in Fig. 2 are not necessarily to scale but have been chosen for ease and clarity of presentation.

3D camera 120 comprises a laser 126 that emits a beam 128 of laser light that enters a transmission optics module 130. Transmission optics module 130 collimates and expands beam 128 to form a thin fan beam 132 of laser light. Fan beam 132 is incident on a scanning mirror 134 along a line 136. Scanning mirror 134 reflects fan beam 132 at a scan angle θ, which is measured between a central ray 138, of fan beam 132 and a line 140. Line 140 is preferably perpendicular to both line 136 and the direction of beam 128. Scan angle θ is preferably changed by rotating scanning mirror 134 about an axis coincident with line 136. This type of structure is commonly used in triangulation type 3D systems. (In some systems a polygonal scanner is used in place of scanning mirror 134 to change scan angle θ).

For each scan angle θ, fan beam 132 illuminates a thin "object" stripe 150 on the surface of object 122. Light from fan beam 132 that object stripe 150 reflects is collected by an appropriate lens system, represented schematically by a lens 144, that focuses the collected light onto pixels 21 of photosurface 20 to form an object stripe image 152 on photosurface 20. Lens 144 has an optic axis 145. Preferably, optic axis 145 of lens 144, the direction of beam 128, central ray 138 and line 140 are coplanar.

Light from fan beam 132 that is reflected from a small region 154 of stripe 150 on object 122 is focused by lens 144 to a corresponding region 156 on object stripe image 152. If the magnitude of scan angle θ is known, three spatial coordinates for region 154 with respect to a convenient coordinate system can be determined from the location of region 156 on photosurface 20, using geometric analysis methods known in the art. The three coordinates locate region 154 in space with respect to photosurface 20 and determine the distance of region 154 from photosurface 20 and the location of region 154 on object 122. The equations that define the three coordinates as functions of scan angle θ and the relative positions of elements of 3D camera 120 are discussed in PCT application PCT/IL97/00370 referenced above.

In order to determine the scan angle θ for a given object stripe image 150, in accordance with a preferred embodiment of the present invention, 3D camera 122 comprises a position reflector 141. Points on position reflector 141 are imaged by lens 144 with the light that they reflect onto pixels 21 that lie in a band 148 of pixels 21 on photosurface 20, *i.e.* the image of position reflector 141 on photosurface 20 is band 148.

At a given scan angle θ, fan beam 132 illuminates position reflector 141 along a thin "position" stripe 142. Light from fan beam 132 reflected from position stripe 142 is focused by lens 144 to form a position stripe image 146 that lies in band 148. The location of position stripe image 146 along band 148 is a function of fan angle θ.

Position reflector 141, is accurately positioned with respect to line 136, lens 144 and photosurface 20. From the known position of these elements the magnitude of scan angle θ can be determined from the location of region 146 on photosurface 20.

To measure distances to regions of object 122, in accordance with a preferred embodiment of the present invention, at a time t = 0 pixels 21 of photosurface 20 are reset and then gated on. Storage capacitors 50 in pixels 21 begin integrating current from their respective flip-flops. Object 122 is then illuminated at a plurality of different scan angles θ. For each scan angle θ at which object 122 is illuminated by fan beam 132, an object stripe image 152 and a position stripe image 146 corresponding to the scan angle θ are formed on photosurface 20. When the light that forms the object stripe image 152 and the position stripe image 146 is incident on photosurface 20, photocurrent is generated in photosensors 44 in pixels 21 that lie in the images. As a result, pixels 21 in the images are gated off and capacitors 50 in pixels 21 in the object stripe image 152 and the position stripe image 146 stop integrating current.

However, because of differences in path lengths from the source of fan beam 132 to pixels 21 in photosurface 20 for different points on object stripe 150 and position stripe image 146, pixels 21 in the object stripe image 152 and the position stripe image 146 are gated off at slightly different times, hereinafter referred to as “stop times”. However, differences in path lengths lead to differences in stop times that are equal to differences in path lengths divided by the speed of light. These time differences are generally very small compared to the time, hereinafter referred to as a “shift time”, that it takes to change the scan angle from one to another of the scan angles at which fan beam 132 illuminates object 122. Furthermore, the maximum difference between stop times for pixels 21 in an object image stripe 152 and a position stripe image 146 corresponding to a same scan angle can be decreased relative to the shift time by reducing the speed at which scan beam 132 is moved from one scan angle to the next scan angle. Therefore, differences in stop times for pixels 21 in an object stripe image 152 and a position stripe image 146 corresponding to a same scan angle are relatively small. On the other hand differences between stop times for pixels 21 in an object stripe image 152 and a position stripe image 146 corresponding to different scan angles are relatively large.

As a result, differences between voltages to which storage capacitors 50 are charged in an object stripe image 152 and a position stripe image 146 corresponding to a same scan angle are small compared to differences between voltages to which storage capacitors 50 are charged in an object stripe image 152 and a position stripe image 146 corresponding to different scan angles. Pixels 21 belonging to a same scan angle can be distinguished from pixels 21 belonging

to different scan angles by the voltage to which their respective storage capacitors 50 are charged.

Pixels 21 in object stripe images 152 and position stripe images 146 are in effect time stamped with the time that they were created, with the time stamp of a pixel 21 being registered in the voltage of the pixel's storage capacitor 50. Pixels 21 belonging to the same scan angle θ bear the same time stamp (to within a maximum difference in stop times for pixels that are illuminated at the same scan angle) while pixels 21 belonging to different scan angels θ bear different time stamps.

Following illumination of object 122 at different scan angles θ a frame of photosurface 20 is grabbed by reading out the voltages of storage capacitors 50. Therefore, when the image frame data is processed all pixels 21 that were illuminated with fan beam 132 at a same scan angle θ can be identified by the charge accumulated on their respective storage capacitors 50, *i.e.* by their respective time stamps.

For each pixel 21 in an object stripe image 152 there is at least one pixel 21 in a position stripe image 146 bearing the same time stamp. Therefore since the scan angle θ for a pixel 21 in a position stripe image 146 is known, the scan angle for each pixel 21 read in the frame is known. As a result, the location in space of each region 154 of object 122 imaged on a pixel 21, the distance of the region 154 from photosurface 20 and its location on object 122, can be determined, in accordance with a preferred embodiment of the present invention.

Fig. 3 schematically shows a photosurface 180 comprised in a 3D camera 182, in accordance with a preferred embodiment of the present invention. 3D camera 182 uses triangulation to determine distances to an object and is shown in Fig. 3 imaging object 122. 3D camera 182 is preferably identical to 3D camera 120 shown in Fig. 2 except that photosurface 180 replaces photosurface 20 of 3D camera 120 and position reflector 140 is preferably replaced by a position sensing device, "PSD" 184.

PSD 184 is accurately positioned with respect to the other elements of 3D camera 182, so that for each different scan angle θ, fan beam 28 illuminates PSD 184 along a thin stripe 186 that is located at a different position along PSD 184. PSD 184 has an output 188 that is connected to a controller 190 and transmits information to controller 190 corresponding to the position of thin stripe 186 on PSD 184. From the transmitted information, controller 190 preferably determines the scan angle θ of fan beam 28.

Photosurface 180 comprises pixels 192, each of which preferably has a pixel circuit 194 shown schematically and greatly magnified. Preferably, photosurface 180 is shielded with

a filter (not shown) that transmits substantially only light having a wavelength that is the same as a wavelength of light radiated by laser 126.

Pixel circuit 194 comprises a photosensor 44 preferably back biased with a voltage Vdd, a comparator 46 and an address switch 196. Photosensor 44 is preferably connected at a node 198 to a positive input 52 of comparator 46 and a bleeding resistor 200 that is preferably connected to ground. A negative input 54 of comparator 46 is connected to a voltage source 58 that maintains negative input 54 at an appropriate reference voltage VR. An output 56 of comparator 46 is connected to address switch 196. When address switch 196 is closed, output 56 of comparator 46, is connected to a read out buss 72.

When light to which photosensor 44 is sensitive is incident on photosensor 44 with sufficient intensity, a photocurrent is generated in photosensor 44 that drives input 52 of comparator 46 above reference voltage VR. In response, comparator 46 generates an appropriate predetermined voltage, hereinafter referred to as a "signal voltage", on output 56 and maintains the signal voltage on output 56 as long as voltage on input 52 remains above the reference voltage VR. If address switch 196 is closed when there is a signal voltage on output 56, the signal voltage is transmitted to readout buss 72. Address switch 196 is controlled by signals that it receives over a switch control line 202. A pixel 192 is said to be "on" when voltage on output 56 of comparator 46 in the pixel is at the signal voltage.

Assume that pixels 192 in photosurface 180 are located by row and column indices i and j respectively and that the particular pixel 192 in the i-th row and j-th column of pixel surface 180 is represented by P(i,j). The direction of increasing row index i and column index j are indicated by arrows 204 and 206 respectively. Photosurface 180 is oriented, in accordance with a preferred embodiment of the present invention, so that columns of pixels 192 are substantially parallel to the plane of fan beam 28.

Switch control lines 202 of all pixels in a same row of pixels 192 in photosurface 180, in accordance with a preferred embodiment of the present invention, are connected to a common "row" select line 210. Switch control lines 202 of pixels 192 in different rows are preferably connected to different row select lines. Row select lines 210 are preferably connected to a row selector 212. Appropriate control signals from row selector 212 transmitted on a particular row select line 210 control all address switches 196 connected to the row select line 210 to open or close simultaneously. Row selector 212 is preferably connected to controller 190 by control lines 213. Controller 190 transmits signals over control lines 213 that control the signals that row selector 212 transmits and determine over which row select lines

the signals from 212 are transmitted. The particular row select line for the i-th row is represented by "RC(i)".

Read out busses 72 of all pixels 192 in a same column of pixels 192 in photosurface 180 are connected to a common "column" signal line 214, in accordance with a preferred embodiment of the present invention. Read out busses 72 of pixels 192 in different columns are connected to different column signal lines 214. Each column signal line 214 is input to an encoder 216 that has outputs 218. Outputs 218 are connected to controller 190. Encoder 216 has a sufficient number of outputs 218 so that signals on outputs 218 are useable by controller 190 to identify over which signal line 214 a signal reaches encoder 216 as long as signals reaching encoder 216 are sufficiently separated in time so that they do not overlap. The particular column signal line 214 to which readout buses 72 of pixels 192 in the j-th column are connected is represented by "CS(j)".

In some preferred embodiments of the present invention, encoder 216 is designed to send an appropriate signal to controller 190 if more than one signal is input to encoder 190 simultaneously. This can be done, for example, by using pulse height discrimination techniques known in the art to determine if more than one signal is received by encoder 216. In some preferred embodiments of the present invention, encoder 216 and/or controller 190 are designed to determine an average column index from column indices of column signal lines 214 from which signals are received simultaneously. The average column index is used as the column index for the received signals.

In other preferred embodiments of the present invention, encoder 216 is designed so that signals sent to encoder 216 simultaneously over column signal lines 214 that are within a certain limited distance of each other are delayed with respect to each other so that no two signals arrive at the encoder simultaneously. In other preferred embodiments of the present invention a plurality of encoders are used to prevent ambiguity in determining over which column signal lines simultaneous signals arrive. For example, in accordance with a preferred embodiment of the present invention, two encoders are used. One encoder is connected to "even" column signal lines 214 and the other is connected to "odd" column signal lines 214 (*i.e.* column signal lines CS(j) for which j is even and odd respectively). As a result simultaneous signals from two adjacent column signal lines are routed to different encoders and can therefore be distinguished. Three or more encoders are similarly useable to receive signals from column signal lines 214, in accordance with preferred embodiments of the present invention. When using "n" encoders, in accordance with a preferred embodiment of the present

invention, preferably, each of any group of n consecutive column signal lines 214 in photosurface 180 is connected to a different one of the n encoders.

Assume that at a particular moment, light is incident with sufficient intensity on photosensor 44 of pixel P(i,j) to trigger comparator 46 of pixel P(i,j) and thereby to turn on the pixel. As a result, there is a signal voltage on output 56 of comparator 46 of pixel P(i,j). Assume further that during the time that output 56 of pixel P(i,j) has the signal voltage, controller 190 controls row selector 212 to transmit a control signal on row control line RC(i) that closes all address switches 196 in pixels P(i,j) located in row i, while leaving address switches 196 open in all other pixels 192. Then pixel P(i,j) will transmit the signal voltage to encoder 216 over column signal line CS(j). In response, if pixel P(i,j) is the only "on" pixel in row i, encoder 216 receives an input from only one column signal line 214 and will therefore generate signals on its outputs 218 that properly identify to controller 190 that the signal it received came from the particular column signal line CS(j). Since controller 190 has closed only address switches 196 in row i, controller 190 correctly determines that pixel P(i,j) is on.

To determine distances to object 122, fan beam 28 is controlled by controller 190 to illuminate object 122 at a plurality of different scan angles θ. At each scan angle θ, light from fan beam 28 illuminates an object stripe 150 on the surface of object 122. Object stripe 150 is imaged with light that object stripe 150 reflects from fan beam 28 along an image stripe 152 of pixels 192 in photosurface 180. As long as object stripe 150 is illuminated by fan beam 28, outputs 56 of comparators 46 for pixels 192 in image stripe 152 are maintained at the signal voltage and pixels 192 in image stripe 152 are on.

Fan beam 28 is preferably very thin so that illuminated object stripe 150 is also thin and so that image stripe 152 is substantially only one or at most a few pixels 192 wide. For simplicity of presentation it is assumed that image stripe 152 is only one pixel 192 wide.

For each scan angle θ controller 190 controls row selector 212 to close and open address switches 196 that are connected to each of row select lines 210, one row select line 210 at a time. When address switches 196 in a row i of pixels 192 are closed by an appropriate signal on row select line RS(i), the signal voltage from a pixel P(i,j) in image stripe 192 that is located on row i and column j (if there is a pixel 192 in image stripe 152 located at "i,j") transmits its signal voltage along the column signal line CS(j). Controller 190 registers the value of the indices i and j of the pixel P(i,j) and then controls row selector 212 to open address switches 196 in row i and close address switches 192 in a different row. The row and column indices of a pixel 192 in image stripe 152 that is located on the different row is then registered

in the same way that the row and column indices of the pixel P(i,j) in image stripe 152 located in row i and column j is registered. The process continues until all rows are "read" and row and column indices corresponding to the locations of all pixels 192 in image stripe 152 for scan angle θ are registered by controller 190.

It is to be noted, that image stripe 152 is assumed to be one pixel wide and that pixel columns are parallel to the plane of fan beam 28, in accordance with a preferred embodiment of the present invention. Therefore, because address switches 196 are turned on by row rather than by column, in accordance with a preferred embodiment of the present invention, when each row is read, encoder 216 receives an input from only one column signal line 214 at a time.

For scan angle θ, in addition to a set of row and column indices for "on" pixels 192 in image stripe 152, controller 190 preferably receives and registers an output signal from PSD 184. The output signal from PSD 184 is preferably used to determine the scan angle θ to which the on pixel indices correspond. Distances to regions of object stripe 150 are then determined from the registered pixel indices and the scan angle θ.

In the claims and description of the present application, each of the verbs, "comprise" and "include", and conjugates thereof, are used to indicate that the object or objects of the verb include but are not necessarily a complete listing of all components, elements or parts of the subject or subjects of the verb.

The present invention has been described using non-limiting detailed descriptions of preferred embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. Variations of embodiments described will occur to persons of the art. For example, in the preferred embodiments described in Figs. 1 and 2 reflected light from an object imaged is used to turn off flip-flops 48 in pixels 21 of photosurface 20. In variations of the described embodiments, light reflected from an imaged object can be used to turn on flip-flops 48. Flip-flops 48 are then subsequently turned off at a convenient time, such as the time at which a frame of photosurface 20 is taken. In the preferred embodiment described in Fig. 3, PSD 184 can be replaced with a reflector, as shown in Fig. 2. The scope of the invention is limited only by the following claims:

CLAIMS

1. A semiconductor surface comprising a plurality of light sensitive pixels, wherein each pixel of said plurality of pixels comprises an electronic circuit formed on or in said semiconductor surface, said circuit comprising:

a photosensor that generates a signal responsive to light incident thereon at an output thereof; and

circuitry that provides a signal responsive to a time lapse between a first time responsive to said signal and a reference time.

2. A semiconductor surface according to claim 1 wherein said circuitry comprises a current integrator that integrates a current during said time lapse.

3. A semiconductor surface according to claim 2 wherein said current integrator comprises a capacitor.

4. A semiconductor surface according to claim 2 or claim 3 wherein said circuitry comprises a switchable source having on and off states, wherein when said switchable source is in said on state said integrator integrates current and wherein when said switchable source is in said off state said integrator does not integrate current.

5. A semiconductor surface according to claim 4 wherein said circuitry comprises a comparator having an output connected to an input of said switchable source, said photosensor output being connected to an input of said comparator such that when light incident on said photosensor has an intensity greater than a predetermined intensity said switchable source changes states.

6. A semiconductor surface according to claim 4 or claim 5 wherein said circuitry switches said switchable source to said off state, at said first time, responsive to said signal from said photosensor.

7. A semiconductor surface according to claim 4 or claim 5 wherein said circuitry switches said switchable source to said on state, at said first time, responsive to said signal from said photosensor.

8. A semiconductor surface according to any of claims 4 - 7 wherein said switchable source is a flip-flop.

9. A semiconductor surface according to any of the preceding claims wherein said circuit is formed as a monolithic integrated circuit.

10. A 3D camera comprising a semiconductor surface according to any of the preceding claims.

11. A 3D camera according to claim 10 comprising:

a light source that illuminates objects in a scene imaged with said 3D camera with at least one light pulse;

wherein for each pixel of said plurality of pixels said reference time is a time at which said at least one light pulse is radiated and said first time is a time at which light from said at least one light pulse reflected by a surface region of said objects is incident on said pixel,

and including circuitry that computes the distance between said pixel and said surface region responsive to said time lapse.

12. A 3D camera according to claim 10 comprising a fan beam wherein the position of said fan beam is defined by a scan angle.

13. A 3D camera according to claim 12 wherein said fan beam illuminates an object at a plurality of different scan angles and said photosensor signals are generated responsive to light reflected by said object from said fan beam to said photosensors and wherein said fan beam moves between scan angles at a rate so that differences between said first times for different pixels illuminated with reflected light from said fan beam at different scan angles are greater than a given time difference and differences between said first times for different pixels illuminated with reflected light from said fan beam at the same scan angle are less than the given time difference.

14. A 3D camera according to claim 13 wherein the time at which said fan beam illuminates said object at each of said plurality of scan angles is known.

15. A 3D camera according to any of claims 12 - 14 comprising a reflector that reflects light to at least one pixel in said semiconductor surface for each of said scan angles and wherein for a given scan angle differences between said first time for said at least one pixel and said first times for pixels illuminated by light from said fan beam reflected by said object are less than said given time difference.

16. A 3D camera according to claim 15 and including circuitry that determines said given scan angle from the location of said at least one pixel.

17. A 3D camera according to any of claims 9 – 16 wherein said reference time is the same for all pixels of said plurality of said pixels.

18. A 3D camera according to any of claims 9 – 16 wherein said reference time is different for at least two pixels of said plurality of pixels.

19. A 3D camera for measuring distances to points on an object comprising:

a semiconductor surface comprising a plurality of light sensitive pixels wherein each pixel comprises a circuit having a photosensor, a switch and an output terminal, wherein said circuit provides a signal on said output terminal only when light is incident on said photosensor and said switch is closed; and

a fan beam that illuminates said object for at least one position of said fan beam so that light from said fan beam is reflected by said object to at least one of said pixels,

wherein for each position of said fan beam, a plurality of said switches are closed simultaneously.

20. A 3D camera according to claim 19 wherein said circuits are formed in or on said semiconductor surface.

21. A 3D camera according to claim 19 or claim 20 wherein said circuits are formed as elements of a monolithic integrated circuit.

22. A 3D camera according to any of claims 19 - 21 comprising signal receiving circuitry having a plurality of inputs and wherein pixels for which said switches are simultaneously

closed have said output terminals connected to different inputs of said signal receiving circuitry.

23. A 3D camera according to claim 22 wherein said plurality of pixels comprises an array of pixels having rows and columns of pixels, wherein each pixel belongs to one row and one column of said array.

24. A 3D camera according to claim 23 wherein said output terminals of pixels in a same column of pixels are connected to a same input of said encoder.

25. A 3D camera according to claim 24 wherein said switches of all pixels in a same row of pixels are simultaneously closed.

26. A 3D camera according to claim 25 wherein switches of pixels in said semiconductor surface are sequentially closed, row by row.

27. A 3D camera according to any of claims 23- 26 wherein rows of said semiconductor surface are parallel to the plane of said fan beam for all positions of said fan beam at which said fan beam illuminates said object.

28. A 3D camera according to any of claims 19 - 27 wherein an output of said photosensor is connected to a contact terminal of said switch.

29. A 3D camera according to any of claims 19 - 27 wherein said circuit comprises a comparator having an input connected to said photosensor wherein, when light having an intensity greater than a predetermined intensity is incident on said photosensor, a signal is generated on an output of said comparator.

30. A 3D camera according to claim 29 wherein said output of said comparator is connected to a contact terminal of said switch.

31. A 3D camera according to any of claims 22 - 30 wherein said signal receiving circuitry comprises an encoder.

32. A method of measuring distances to regions on an object comprising:

providing a semiconductor surface having a first plurality of light sensitive pixels;

illuminating said object with light from a fan beam of light having a position defined by a scan angle;

sensing signals from pixels on said semiconductor surface that are illuminated with light reflected from said fan beam by said object by simultaneously interrogating a second plurality of pixels comprised in said first plurality of pixels;

determining a scan angle for pixels that provide signals;

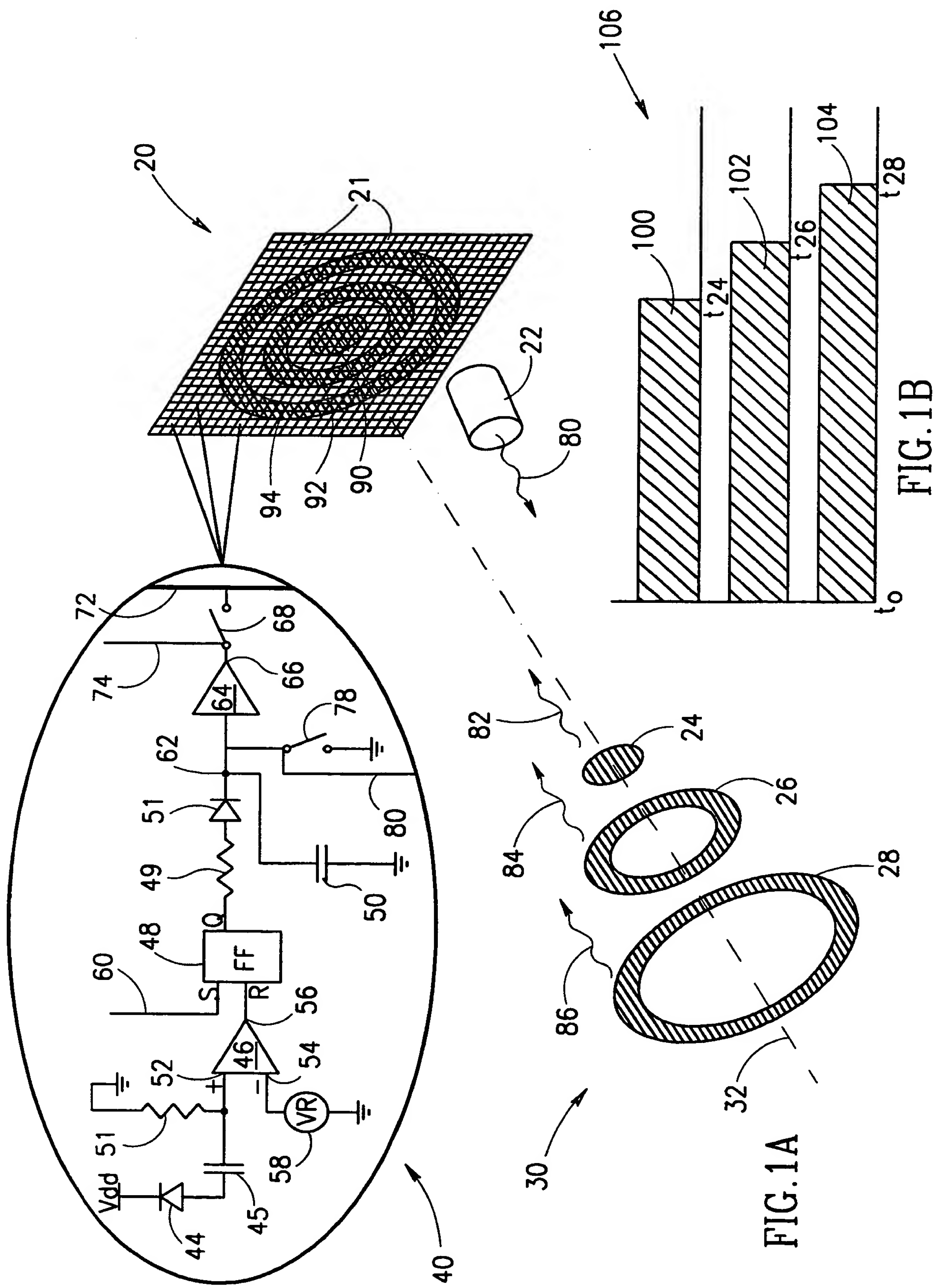
using locations of pixels that provide signals and said determined scan angles to determine distances to regions of said object.

33. A method according to claim 32 wherein said first plurality of pixels are arranged in a rectangular array of rows and columns pixels.

34. A method according to claim 33 wherein all pixels in a row of pixels are interrogated simultaneously.

35. A method according to claim 34 wherein pixels in said first plurality of pixels are interrogated sequentially, row by row.

36. A method according to any of claims 33 - 35 comprising providing a signal sensing means and wherein sensing signals comprises sensing signals from all pixels in a column of pixels on a same input of said sensing means.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FF
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Vdd
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VR
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86
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FIG.1A

FIG.1B

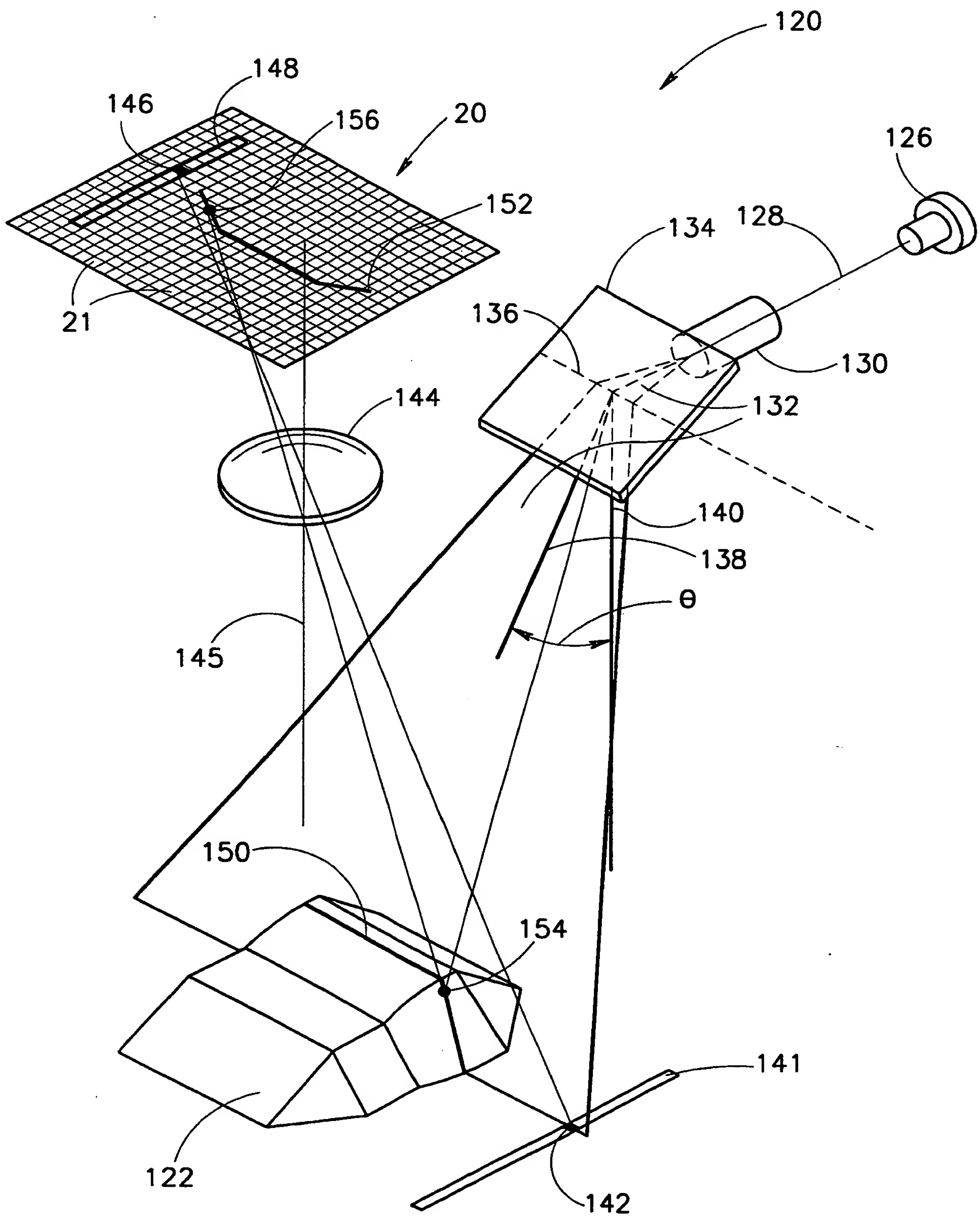
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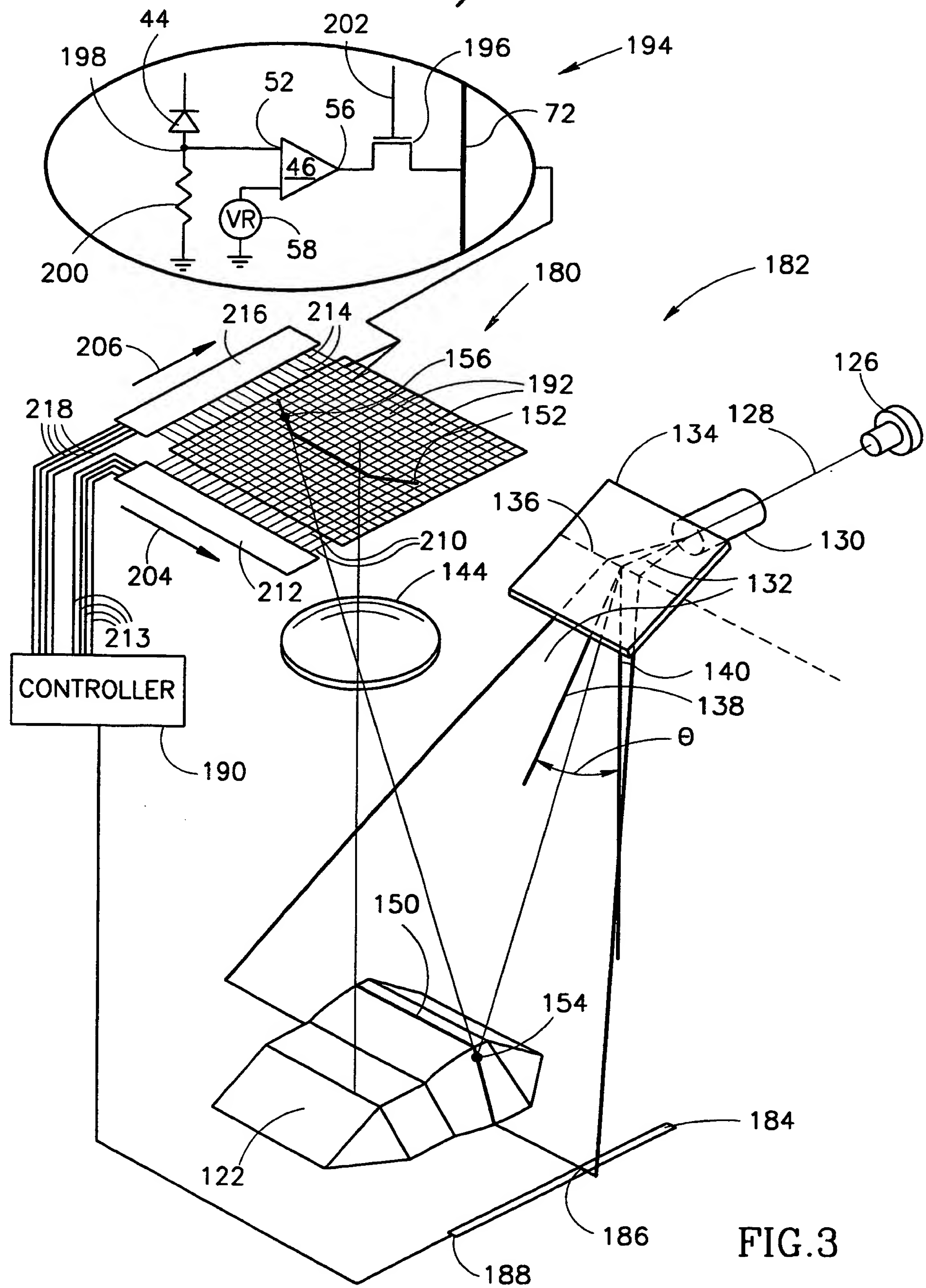
FIG.2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198
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FIG.3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 98/00611

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01C3/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01C G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 4 979 816 A (WHITE STEVEN J) 25 December 1990 (1990-12-25) the whole document	1-3,9 10-12, 17, 19-21, 32,33
Y	US 5 682 229 A (WANGLER RICHARD J) 28 October 1997 (1997-10-28) column 6, line 53 - column 7, line 47	10-12, 17, 19-21, 32,33
A	US 5 430 290 A (MERLE JEAN-PIERRE ET AL) 4 July 1995 (1995-07-04) column 7, line 36 - column 8, line 2; figure 7	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 August 1999	03/09/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hoekstra, F

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 98/00611

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 4979816	A	25-12-1990	NONE			
US 5682229	A	28-10-1997	US	5870180	A	09-02-1999
US 5430290	A	04-07-1995	FR	2707394	A	13-01-1995
			DE	69404775	D	11-09-1997
			DE	69404775	T	18-12-1997
			EP	0633457	A	11-01-1995
			ES	2106470	T	01-11-1997

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

To:
FENSTER & COMPANY PATENT
ATTORNEYS, LTD
P.O.Box 10256
Petach Tikva 49002
ISRAEL

RECEIVED
14-09-1999
FENSTER & Co

	Date of mailing (*day/month/year*) 03/09/1999
Applicant's or agent's file reference 001/00620	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/IL 98/00611	International filing date (*day/month/year*) 16/12/1998
Applicant 3DV SYSTEMS, LTD. et al.	

1. [X] The applicant is hereby notified that the International Search Report has been established and is transmitted herewith.

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the International Application (see Rule 46):

When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the International Search Report; however, for more details, see the notes on the accompanying sheet.

Where? Directly to the International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Fascimile No.: (41-22) 740.14.35

For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no International Search Report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   [ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   [ ] no decision has been made yet on the protest: the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bakari Mwamboga

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the PCT Applicant's Guide, a publication of WIPO.

In these Notes, "Article", "Rule", and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international pbulication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped), whether

- (i) the claim is unchanged;
- (ii) the claim is cancelled;
- (iii) the claim is new;
- (iv) the claim replaces one or more claims as filed;
- (v) the claim is the result of the division of a claim as filed.

The following examples illustrate the manner in which amendments must be explained in the accompanying letter:

1. [Where originally there were 48 claims and after amendment of some claims there are 51]:
"Claims 1 to 29, 31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers; claims 30, 33 and 36 unchanged; new claims 49 to 51 added."

2. [Where originally there were 15 claims and after amendment of all claims there are 11]:
"Claims 1 to 15 replaced by amended claims 1 to 11."

3. [Where originally there were 14 claims and the amendments consist in cancelling some claims and in adding new claims]:
"Claims 1 to 6 and 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
"Claims 7 to 13 cancelled; new claims 15, 16 and 17 added; all other claims unchanged."

4. [Where various kinds of amendments are made]:
"Claims 1-10 unchanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended claim 14; claim 17 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

"Statement under article 19(1)" (Rule 46.4)

The amendments may be accompanied by a statement explaining the amendments and indicating any impact that such amendments might have on the description and the drawings (which cannot be amended under Article 19(1)).

The statement will be published with the international application and the amended claims.

It must be in the language in which the international appplication is to be published.

It must be brief, not exceeding 500 words if in English or if translated into English.

It should not be confused with and does not replace the letter indicating the differences between the claims as filed and as amended. It must be filed on a separate sheet and must be identified as such by a heading, preferably by using the words "Statement under Article 19(1)."

It may not contain any disparaging comments on the international search report or the relevance of citations contained in that report. Reference to citations, relevant to a given claim, contained in the international search report may be made only in connection with an amendment of that claim.

Consequence if a demand for international preliminary examination has already been filed

If, at the time of filing any amendments under Article 19, a demand for international preliminary examination has already been submitted, the applicant must preferably, at the same time of filing the amendments with the International Bureau, also file a copy of such amendments with the International Preliminary Examining Authority (see Rule 62.2(a), first sentence).

Consequence with regard to translation of the international application for entry into the national phase

The applicant's attention is drawn to the fact that, where upon entry into the national phase, a translation of the claims as amended under Article 19 may have to be furnished to the designated/elected Offices, instead of, or in addition to, the translation of the claims as filed.

For further details on the requirements of each designated/elected Office, see Volume II of the PCT Applicant's Guide.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 001/00620	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/IL 98/00611	International filing date *(day/month/year)* 16/12/1998	(Earliest) Priority Date *(day/month/year)*
Applicant 3DV SYSTEMS, LTD. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 2 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

[ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readble form.

[ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

[X] the text is approved as submitted by the applicant.

[ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

[X] the text is approved as submitted by the applicant.

[ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1a

[ ] as suggested by the applicant.

[ ] because the applicant failed to suggest a figure.

[X] because this figure better characterizes the invention.

[ ] None of the figures.